

An ultra-fast x-ray source for fsec dynamics

Overview

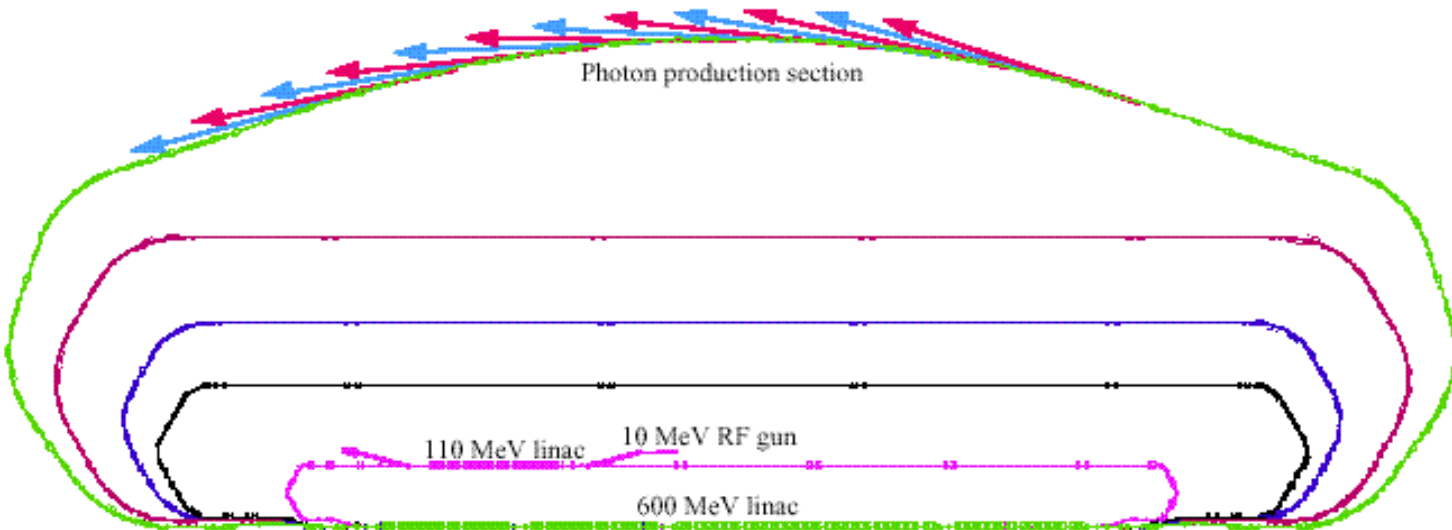
John Corlett

Femtosource Advisory Committee Meeting

December 7th 2001

An ultra-fast x-ray source for fsec dynamics

- User facility based on recirculating linac



- Science driven proposal for a 4th generation light source
- “niche” facility for structural dynamics studies
 - High flux 3×10^{10} photons/sec/0.1%bw
 - X-ray pulse duration 60 fsec FWHM
 - Tunable 1 - 12 keV
 - Repetition rate 10 kHz (commensurate with structural dynamics pump-probe)
- The scale of such a facility will be assessed as part of this work, but it is expected to be in the range of a \$100M to \$150M capital project



This project is an extension of the Berkeley fs x-ray program

- 300 fsec Thompson scattering
 - R.W.Schoenlein et al., Science 274, 1996; A.H.Chin, et al. PRL 83, 1999
 - psec streak camera detection using synchrotron x-rays
 - A.M.Lindenberg, et al., PRL 84, 2000
 - laser induced 100 fsec beam slicing in a synchrotron
 - R.W. Schoenlein et al., Science 287, 2000
 - proposed slicing using an undulator source
 - R.W. Schoenlein , R.W.Falcone, proposal to DOE, 2000
 - studies of atto-second laser driven electron beam source
 - A.A.Zholents. et al., PAC 2001
 - all-optical compact high gradient electron accelerator
 - W.Leemans et. al., PAC 2001
 - **linac driven ultra-fast x-ray source**
 - H.Padmore et al., SRN 2001; J.N.Corlett et al., PAC 2001
-
- **Driven by a strong local fs optical spectroscopy community**



What is the need for such a facility?

- fs lasers have had tremendous impact and revolutionized many areas of physics, chemistry and biology
 - Excellent temporal resolution, limited spatial resolution
 - Optical probes measure the extended electronic structure over many atoms
- A fs x-ray source provides a new tool for measuring atomic positions
 - Standard X-ray techniques
 - X-ray absorption
 - X-ray diffraction

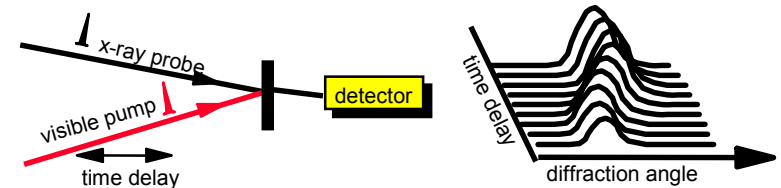
With XAS and XRD measurements + ultra-short pulse x-ray facility, we will be able to directly view atomic motion on the fundamental timescale of 1 vibrational period (~ 100 fsec)

Strong scientific case for a dedicated fs x-ray user facility

Time resolved experiments at fundamental time scales

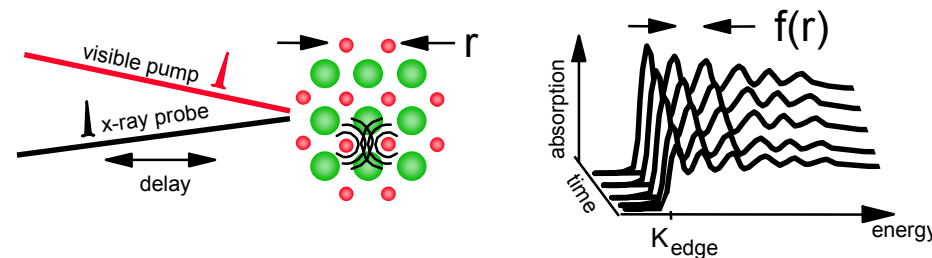
- **Ultrafast structural dynamics in solids**
 - Order/disorder transitions (melting)
 - Solid-solid phase transitions
 - Surfaces
- **Ultrafast molecular dynamics**
 - Structural dynamics of the transition state
 - Solvent/solute interactions (solvent structure)
- **Ultrafast processes in biology**
- **Atomic and molecular physics**
- **Magnetization and spin dynamics**
- **Dynamics in warm dense matter**

Time-resolved x-ray diffraction



Ordered crystals - phase transitions, coherent phonons

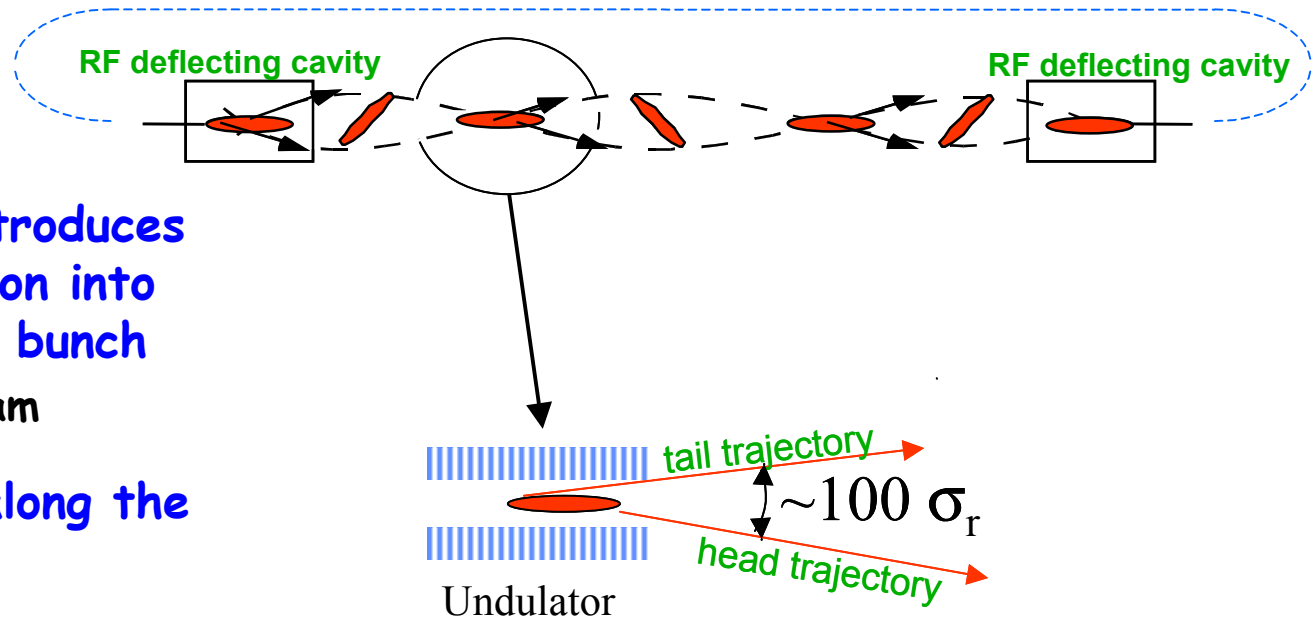
Time-resolved EXAFS, NEXAFS, surface EXAFS



Complex/disordered materials - chemical reactions
surface dynamics
bonding geometry

Science case will not be further presented here

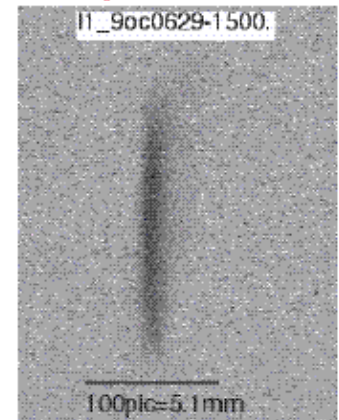
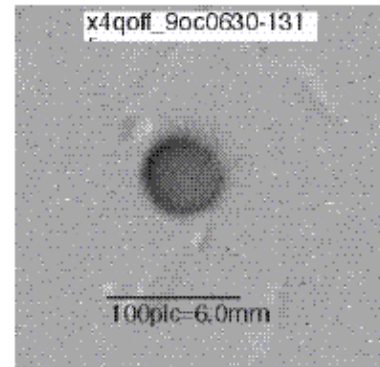
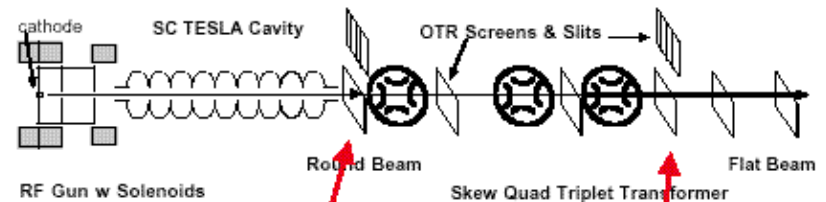
How we produce femtosecond x-ray pulses



- Deflecting cavity introduces angle-time correlation into the (short) electron bunch
 - “crabbing” the beam
- Electrons oscillate along the orbit
- Crystal x-ray optics take advantage of the position-time correlation, or angle-time correlation to compress the pulse

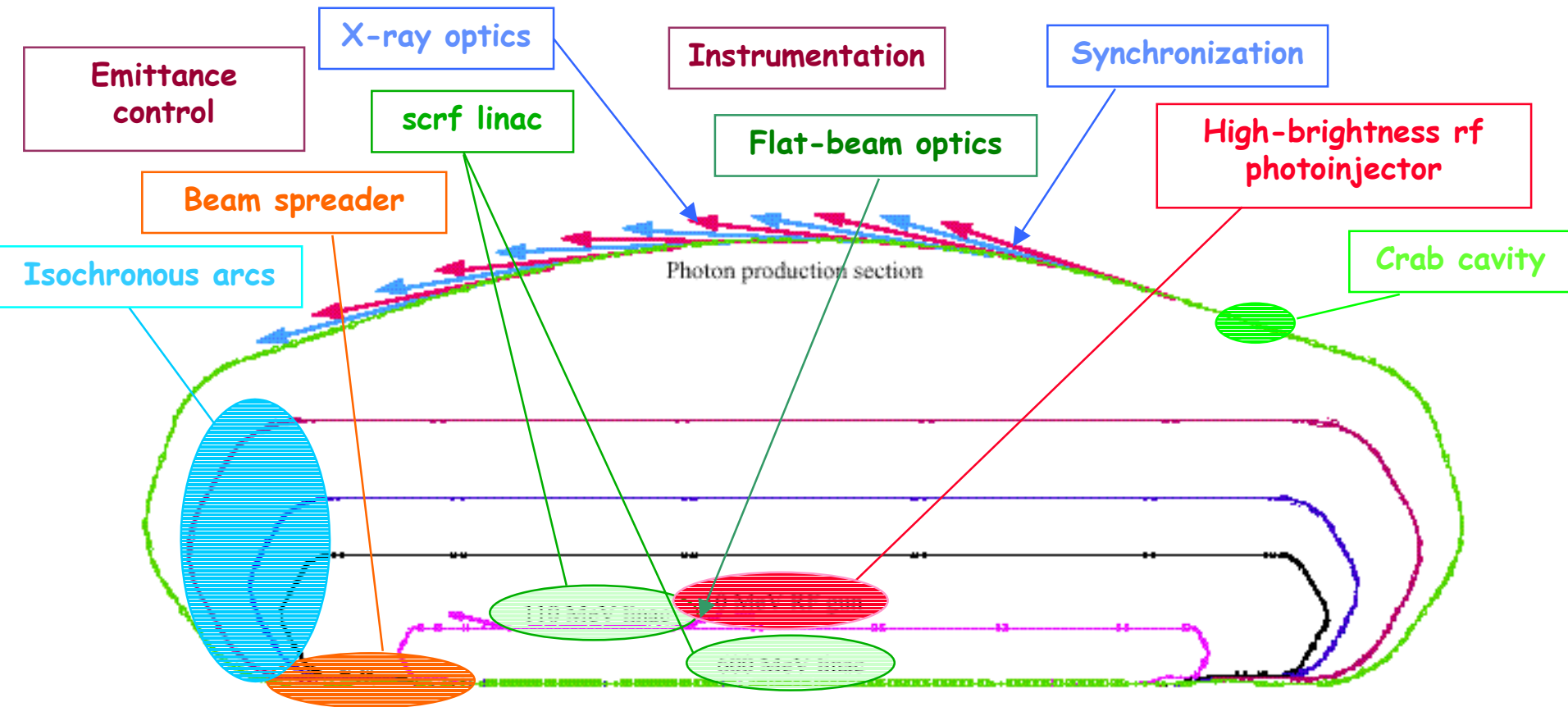
How we produce femtosecond x-ray pulses

- The “crabbed” beam technique requires a beam with small emittance in the tilted plane
 - “Flat-beam”
- Produce electrons in solenoidal magnetic field at cathode
- Quadrupole channel transforms “rotating” beam into “flat” beam
- 50:1 emittance ratio demonstrated for 1 nC at A0 - Fermilab/NICADD Photoinjector Laboratory (FNPL)
- *Must maintain this emittance through machine*



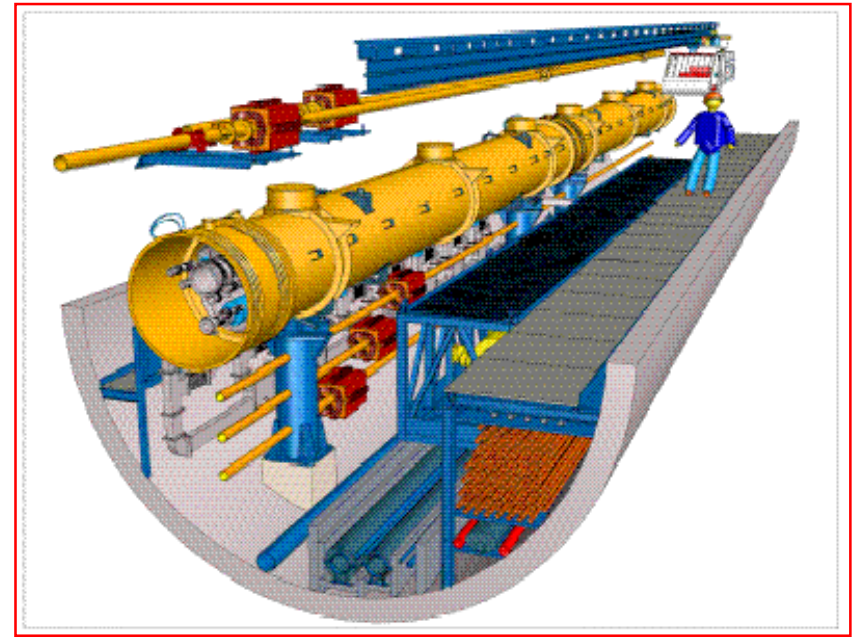
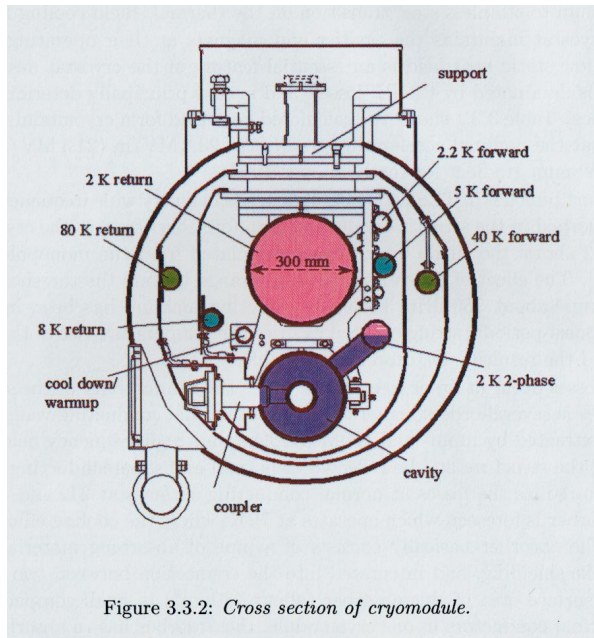
Ultra-fast x-ray source machine studies

- Initial feasibility study report - LBNL-48171
 - Key technologies and physics issues identified
 - "Conventional" accelerator techniques to produce fs pulses - no "show-stoppers"
 - Design philosophy "flexible" machine parameters
 - Collaborations make good use of available resources and expertise developed elsewhere



Superconducting rf - TESLA modules

- We base our linac design on TESLA scrf modules
 - Cost effective
 - Footprint compatible with Berkeley lab site
 - Demonstrated successful technology
 - CEBAF energy upgrade cryomodule also attractive



TESLA superconducting RF modules

Superconducting rf

Femtosource linac parameters:

E_{acc}	20 MV/m
Frequency	1.3 GHz
Operation mode	CW
Quality factor	1×10^{10}
RF power loss/cavity	42 W
Cavity length	1.038 m
Module length	12 m
Cavities/module	8
Beam current	0.04 mA
Bandwidth	200 Hz
$Q_{external}$	6.5×10^6
RF power/ module	128 kW
2 K dynamic load	1.5 kW

Plus 6.5 MV transverse beam voltage in
3.9 GHz deflecting scrf cavities

- Similar technology at Fermilab

9-cell superconducting cavity for TESLA
Gradient $E_{acc} = 23$ MV/m

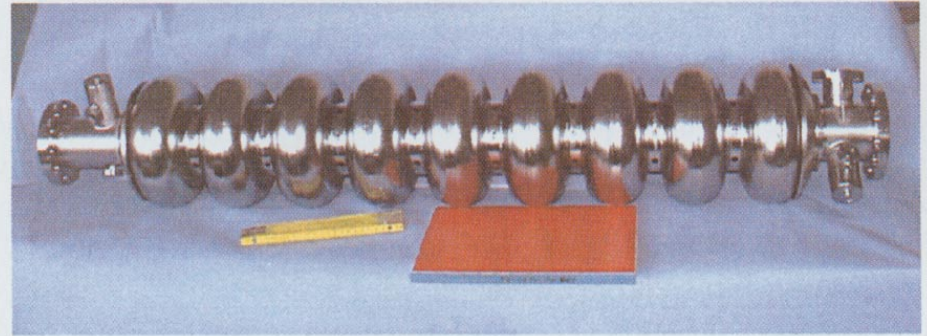
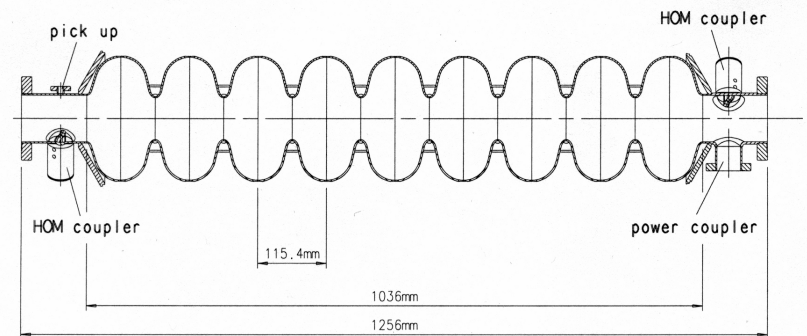


Figure 1.1.1: The 9-cell niobium cavity for TESLA.





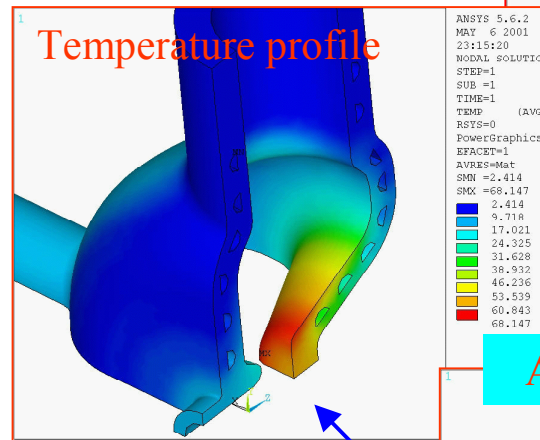
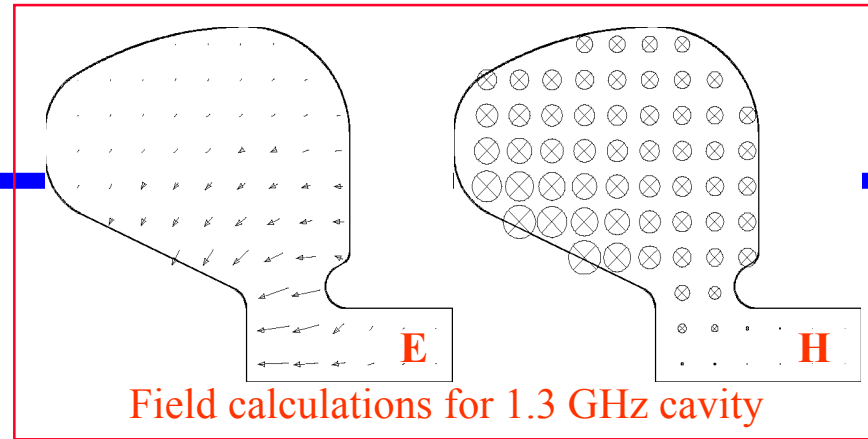
RF photocathode gun

- Design based on extrapolation of experience from Fermilab/NICADD Photoinjector Laboratory (FNPL)
- Other facilities operate high-brightness RF photocathodes too
 - BNL
 - ANL

Energy	10 MeV
Charge	1 nC
Normalized rms horizontal emittance	20 mm-mrad
Normalized rms vertical emittance	0.4 mm-mrad
Energy spread at 10 MeV	15 keV
Pulse length (uniform distribution)	10 ps
Repetition rate	10 kHz
RF gun parameters:	
RF frequency	1.3 GHz
Peak electric field on a cathode	60 MV/m
Laser parameters:	
Wavelength (3-rd harmonic of Ti:sapphire laser)	267 nm
Pulse energy	100 μ J
Pulse length (FWHM)	10 ps

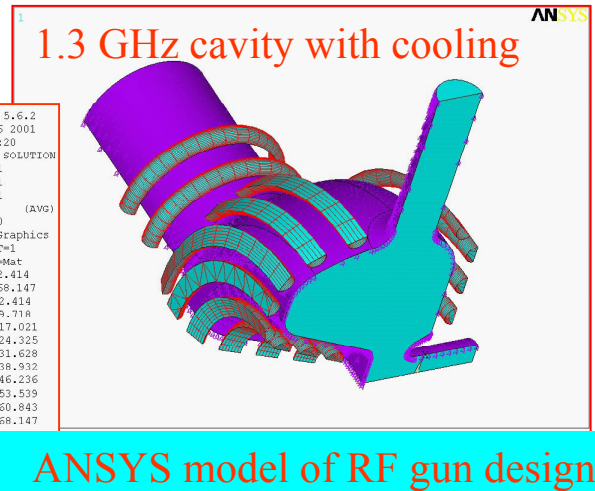
RF photocathode gun

- Accelerating field at cathode needs to be $\sim 60 \text{ MVm}^{-1}$ to achieve good beam quality
- Gun repetition rate then limited by cavity wall heating
- Design cavity for optimal voltage, and wall power density $< 100 \text{ Wcm}^{-2}$

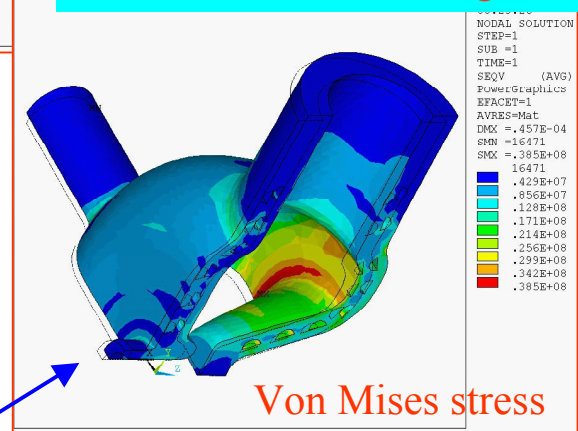


Maximum 68° above ambient temperature

Maximum stress 5500 psi safely below "limit" of 18000 psi for 10,000 cycles in Cu



ANSYS model of RF gun design



- Some of the proposed technology is new to Berkeley
 - Superconducting RF technology
 - RF photoinjector technology
 - Recirculating linac operations

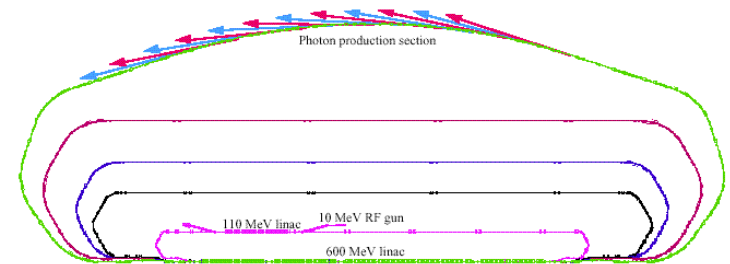
} ⇒ new technology for LBNL
- We can use existing technologies but must invest in bringing them to Berkeley
- Collaborate with industry and other laboratories to bring existing technologies to Berkeley quickly and efficiently
 - AO - Fermilab/NICADD Photoinjector Laboratory (FNPL) ✓
 - TJNAF - scrf linac and recirculating operations experience ✓
 - TESLA / ACCEL - scrf based linac

Ultra-fast x-ray source machine studies

- Plan for FY'02 is to show the feasibility of our proposal, with focus on key questions that may influence design choices and costs

- High-brightness RF gun
- Flat beam production
- Superconducting rf systems
- Cryogenic systems
- Deflecting cavities
- Lattice and single-particle dynamics
- Emittance control and collective effects
- Jitter sources and synchronization issues
- Develop cost estimate
- Site selection

Particular attention for this review



- The deliverable is a technical feasibility report of ~100 pages describing the machine, with a preliminary cost estimate, comparison of sites, and R&D plan



Funding to prepare the case for a femtosource facility at Berkeley

- The project is supported primarily by LDRD in FY'02
 - \$500k operations funds allocated
 - \$300k strategic funds expected
 - Supports ~ 4.4 FTE staff + contract engineering labor and GSRA + travel, M&S
 - Additional support from ALS + other divisions?
 - 2 FTE contributed from ALS staff - accelerator physics and engineering
 - *Science driven*
 - ALS + MSD staff developing the science case - not covered here
 - 1.7 FTE science case development + travel, workshops
 - Machine studies mostly physics - "advanced feasibility study"
 - Produce ~100 page feasibility study by end FY'02
 - Light on engineering, not ready for CDO
 - 1.9 FTE accelerator physics studies
 - 0.8 FTE engineering
 - » Estimate ~ 9 man-yr from now required for CDO preparation

Fractional FTE's for
the most part



Physics studies priority over engineering at the current level of funding

- Our plan is to pursue feasibility studies with less engineering support than we would ideally like
 - Prefer at least one additional FTE engineering effort
- We need the physics studies to evolve, demonstrate feasibility, and define (some of) the problems
- Available engineering effort focussed on key areas
 - Magnet design - allow reasonable cost estimate
 - Cryogenics - determine feasibility, allow reasonable cost estimate
 - WBS and cost estimate
 - Site selection - Berkeley site will be a protracted development
 - Engineering model / layout
 - Project development and strategies for DOE funding
- We defer additional engineering studies until FY'03, when we will need to pick up tasks to prepare for CDO
 - RF systems
 - Vacuum systems
 - Cryogenics
 - Power supplies
 - Magnet details, etc

} "demonstrated" technology that can be deferred



What we want to achieve in the next 12 months

- The deliverable is a technical feasibility report of ~100 pages describing the machine, with a preliminary cost estimate, comparison of site issues, and R&D plan
 - Convince peers that designs chosen are reasonable and cost effective
 - Can achieve the user-specified parameters - flux, temporal and amplitude stability
 - Defensible cost estimate
 - Develop technologies that allow the facility to be built
 - Pursue and enhance collaborations in rf photocathodes, scrf, and flat-beam production
 - Identify areas for additional engineering study
 - Vacuum systems
 - Cryogenics
 - Power supplies
 - Produce a plan for completing R&D necessary
 - High-brightness, high-repetition rate rf photocathode gun
 - High-frequency scrf deflecting cavity
 - Emittance control
 - cw scrf
 - Synchronization
 - Outline site options
 - Bevatron - decommissioning ?



Timescales

- **Fall 2000** LDRD studies begin (storage ring based)
 - **Spring 2001** Femtosource Project in LBNL institutional plan
 - **Summer 2001** Project presented to DOE BES
Initial feasibility report - LBNL 48171
 - **Early 2002** LBNL proposal on BESAC agenda
 - **Spring 2002** International workshop on ultrafast science
 - **Fall 2002** Scientific case document and *machine feasibility study* submitted to DOE BES
 - **FY 2003** Additional engineering studies, preparation for CDO
CDO review
Continue development of rf photocathode - high rep-rate rf structure
Continue to develop scrf expertise - collaborations with other labs
 - **FY 2004** CDR funded
 - **FY 2006+** Construction
- Scope of this review



Summary

- We propose a facility, based on recirculating linac, for dedicated femtosience studies
- Design appears feasible
 - Initial feasibility study - no show-stoppers
- This year will produce a machine feasibility report
- Need demanding, expensive new technologies at Berkeley Lab
 - scrf
 - High brightness rf photocathode guns
 - Need R&D programs to develop to our needs
 - Buy the technology and do not plan for extensive technical development facilities
 - Collaborations extremely important
- Berkeley Lab directorate strongly supports the project
 - Continuation of Berkeley Lab history in fs science
- Need additional in-house resources to prepare for DOE project review

We will appreciate knowing your thoughts on our work and plans



Charge to committee

Evaluate the technical R&D and project development plans for FY'02 accelerator physics and machine studies, in preparation of a feasibility study for an ultra-fast x-ray science facility, with a view to preparing for CDO submission in the following year.

Provide guidance on appropriateness of chosen areas of study given realistic budgets and resources, and suggestions for other directions if appropriate.